Detection of X-rays and study of the Spaghetti nebula with SRG/eROSITA

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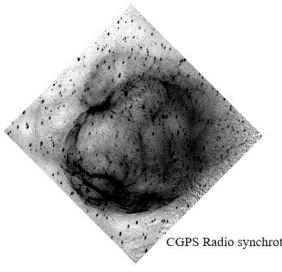
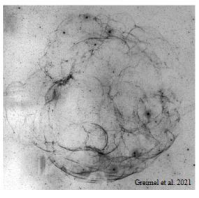
Introduction

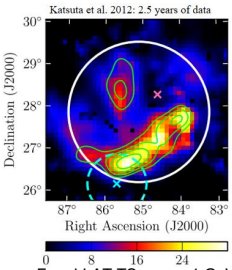
The apparent size of evolved supernova remnants (SNR) depends on their distance. In close proximity to Earth (hundreds of parsecs), they can reach degree-scale sizes. Current imaging X-ray instruments have a limited field of view (FoV), making them difficult to study in X-rays. In many cases, imaging survey data is the only option. In this respect, eROSITA offers a unique opportunity to study such objects with unprecedented sensitivity. In this category, Simeis 147 or Spaghetti nebula is a classic example. The Spaghetti nebula is a supernova remnant studied extensively across the entire electromagnetic spectrum, from radio to GeV γ-rays, except in X-rays.



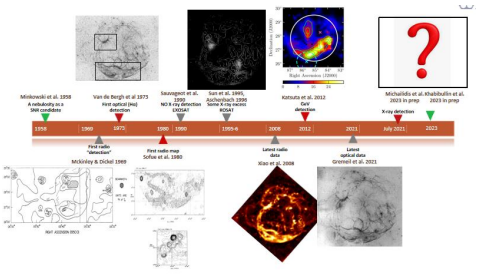
CGPS Radio synchrotron



Background-corrected Hα (Hα-filter)
IGAPS (IPHAS+UVEX)



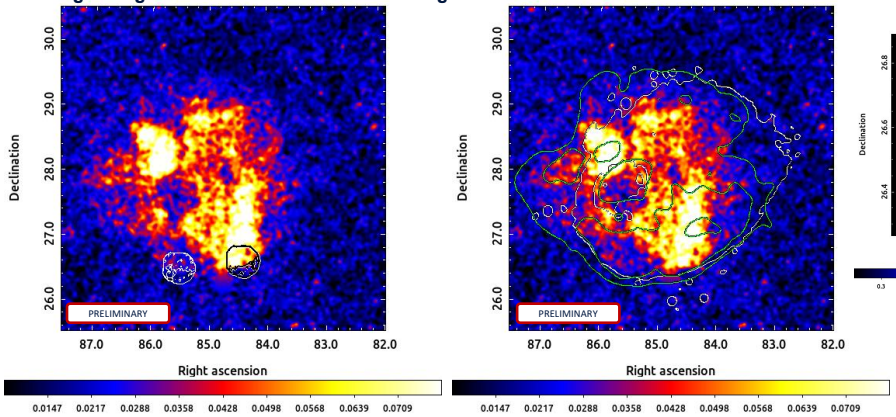
Fermi-LAT TS map: >1 GeV

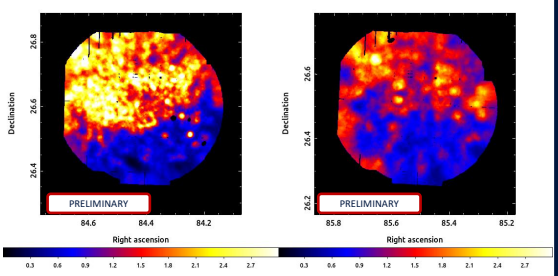


Detection timeline

Main finding and X-ray imaging analysis

In this work, we report the first firm detection of the Spaghetti nebula in X-rays using eRASS data from the first four completed eROSITA All-Sky Surveys, eRASS:4. Falling near the Galactic anti-center, morphologically similar to the Vela SNR, and with an approximate angular size of ~3°, Spaghetti nebula is among the largest SNRs ever detected in X-rays. In the interior of the remnant the emission is well correlated with both radio synchrotron and Hα emission, including a void structure in the East of the SNR where the emission consistently drops in all three wavebands. In addition, we also report results on the analysis of yet unpublished XMM-Newton observations that cover small portions of the SNR, which are found to be in good agreement with the eROSITA findings.



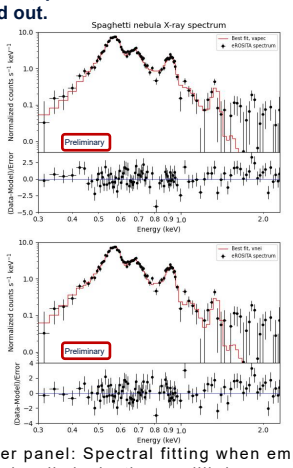


XMM-Newton intensity maps: PN, MOS1, MOS2 merged+adaptively smoothed+point source removed. Left panel: XMM-Newton observation ID: 0693270401. Right panel: XMM-Newton observation ID: 0693270301

eRASS:4 intensity sky maps [counts/pixel] in the 0.5-1.0 keV energy range, with point sources removed. Left panel: 693270301, 0693270401 XMM-Newton observations as white and black contours respectively. Zero level contour indicates the observation FoV, whereas first level contour represent X-ray emission of identical scale for both observations. Right panel: CGPS radio synchtroton data, as white contours, Full Sky Hα data (6' FWHM), as green contours

X-ray spectra

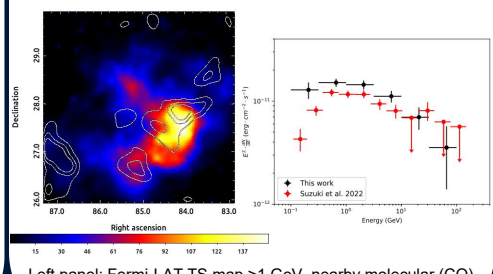
eRASS:4 background subtracted spectral analysis results in the 0.3-2.3 keV energy range. TM5 and TM7 data have been excluded because of known instrumental issues at low energies; point source emission has been filtered out.



Upper panel: Spectral fitting when employing a collisionally ionization equilibrium model (CIE), tbabs(vapec) in Xspec notation. Lower panel: Spectral fitting when employing a non-equilibrium ionization collisional plasma model (NEI), tbabs(vnei) in Xspec notation

Fermi-LAT GeV data

We employed ~14.5 years of 4FGL-DR3 data to verify the association of the extended GeV source 4FGL J0540.3+2756e or FGES J0537.6+2751 with the remnant. In particular, we provide a significantly impoved view of the remnant in the GeV band utilizing 12 additional years of data in comparison to Katsuta et al. (2012), and an updated spectrum in comparison to Katsuta et al. (2012), Suzuki et al (2022) who reported highly consistent spectral results. Two molecular (CO) clouds have been detected in the central and Southern parts of the remnant. In the light of the new GeV data an apparently good correlation between GeV emission and cold gas tracers is obtained.



Left panel: Fermi-LAT TS map >1 GeV, nearby molecular (CO) clouds as white contours. Right panel: GeV SED in the 0.1-100 GeV energy range

Discussion

- **The X-ray emission is predominantly soft with a strong detection between 0.5-1.0 keV, no excess photons are detected above 2.0 keV. Purely thermal X-ray spectra, exhibiting O, Ne, and Mg emission lines whereas lacking high-Z elements, best-fitted with either a CIE model of ~0.11 keV, and an absorption column density of $\sim 0.52 \cdot 10^{22}\ \mathrm{cm}^{-2}$ or a NEI model of ~0.21 keV temperature, and an absorption column density of $\sim 0.33 \cdot 10^{22}\ \mathrm{cm}^{-2}$. It is noteworthy that both models provide poor fits when the elemental abundances of O, Ne, and Mg are fixed to solar values, thus we let them vary when fitting, while a significantly different absorption column density N_H value is obtained based on the nature of the X-ray plasma considered. We claim that the remnant is O-rich (and likely of core-collapse type) making it the second O-rich evolved SNR after G292.0+1.8 in our Galaxy. No significant temperature variation across the remnant has been measured in the current analysis.**
- **XMM-Newton analysis results are in good agreement with eROSITA findings (in terms of image and spectral analysis). Overall, the X-ray, optical (Hα) and radio synchrotron emission is well correlated across the remnant - except for the Western edge.**
- **Robust GeV detection, up to 12σ, of the remnant utilizing ~14.5 years of Fermi-LAT data. Likely association of the remnant with the presence of 2 molecular clouds (CO emission), consistent with the interpretation of the GeV emission as proton-induced.**